Technological Capabilities of a Special Strategy for Processing Cycloidal Helical Surfaces with a Non-Profiled Tool

Aleksandr Aleksandrovich Goncharov (✉ al.goncharov@bmstu.ru)

Bauman Moscow State Technical University

Aleksandr Sergeevich Vasiliev

Bauman Moscow State Technical University

Research Article

Keywords: processing strategy, technological capabilities, processing on CNC machines, non-profiled tool, cycloidal helical surface.

Posted Date: February 12th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-189911/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Technological Capabilities of a Special Strategy for Processing Cycloidal Helical Surfaces with a Non-Profiled Tool

GONCHAROV Alexander Alexandrovich ^{1a},

VASILIEV Alexander Sergeevich ^{1b}

¹Bauman Moscow State Technical University, 2nd Baumanskaya St., 5, bldg. 1, Moscow, Russian Federation, 105005

^a al.goncharow@yandex.ru, ^b vas@bmstu.ru

Abstract. The working bodies of screw volumetric machines are complex-profile cycloidal screw surfaces. This article deals with the problem of technological preparation for the production of such surfaces, associated with the uncertainty of the technological capabilities of a special processing strategy. To solve this problem, an analytical expression of the criterion was proposed, which makes it possible to assess the applicability of the processing strategy for the given geometric parameters. The adequacy of the proposed criterion is confirmed by machine and natural experiments.

Keywords: processing strategy, technological capabilities, processing on CNC machines, non-profiled tool, cycloidal helical surface.

Introduction

Complex-profile cycloidal screw surfaces found application in various fields of industry. The most typical representatives are the working bodies of single-screw volumetric machines for pumping high-viscosity oil products (Fig. 1) [1,2]. Such cycloidal screw surfaces are one of the most labor-intensive surfaces to manufacture. The processing of these surfaces using modern computer numerical control (CNC) equipment can significantly reduce the labor intensity of technological preparation of production in comparison with methods based on the use of profiled tools, in which the shaping of the surface occurs by copying [3,4,5].

Fig. 1. Screw pump for pumping oil products

The trend of the last few years is the use of single-screw volumetric machines for the needs of high-precision dosing of high-viscosity substances. To solve this technological problem, a new class of equipment was proposed: high-precision single-screw dispensers [6]. The working body of these dispensers is a precision miniature gerotor pair, consisting of a polymer cage and a steel rotor (Fig. 2). A feature of this pair is the increased requirements for shape accuracy, as well as the miniature dimensions of these surfaces: the cross-sectional diameter of the screw rotor often ranges from 3 to 8 mm.

Fig. 2. Section of high-precision single-screw dispenser

Earlier it was shown that the shaping of these miniature surfaces by the methods usual for larger-sized products is practically impossible due to the low rigidity of the workpiece being processed [7,8]. However, in [9, 10], a special strategy was proposed for processing cycloidal helical surfaces with different types of cross-section, which allows ensuring the required shape accuracy for given cross-section diameters (Fig. 3).

Fig. 3. Scheme of processing a helical surface according to a special strategy and an example of a tool path

Formulation of the problem

The previously proposed processing strategy allows obtaining a tool path according to a formatted algorithm that uses data on the geometry of the tool and the machined surface in a parametric form. On the basis of this algorithm, an automated programming system was created that allows obtaining the G-code of the control program for a helical surface with arbitrary parameters. To obtain the control program code in this way, a three-dimensional model of the processed surface is not used, which makes it possible to reduce the labor intensity of technological preparation of production. However, such an analytical calculation algorithm does not allow checking the trajectory for the absence of penetration into an already processed surface. The experience of using this algorithm has shown that at certain ratios of the section diameter, pitch, eccentricity of the helical surface and the cutter diameter, the specified surface profile may not be provided during processing. Fig. 4a shows the result of processing a double-helical surface, corresponding to the specified characteristics. In Fig. 4b and 4c, you can see the cross-section of a double-helical surface with obvious deviations from the given cross-sectional profile.

Fig. 4. The processing results corresponding to the specified parameters (a) and having form deviations (b, c)

The results obtained showed that the proposed mathematical model makes it possible to obtain an adequate trajectory not for any input parameters. There are geometric restrictions on the extreme relationship between the section diameter, pitch, eccentricity of the helical surface and the cutter diameter, at which the degeneration of a given profile of the cycloidal helical surface will not occur. Determination of these constraints will allow timely identification of situations when the selected design and technological parameters go beyond the technological capabilities of the strategy.

Identification of technological capabilities

For the analytical determination of the limiting conditions under which the algorithm works correctly, it is necessary to refer to the mathematical processing model proposed earlier [10]. Fig. 5 and Fig. 6 schematically shows the relative position of the cutter and the cross-section of the treated surface. Analyzing this scheme, the following necessary condition for the adequacy of the mathematical model can be distinguished:

$$Z_i = -(e + r) \cdot \sin 45^\circ \cdot \left(1 - \frac{t}{A1+45^\circ}\right) + \Delta Z \geq 0, \text{ at } t = A1, \quad (1)$$

where $\Delta Z = -\Delta Y_2 \cdot \sin \gamma$;

$$\Delta Y_2(t) = r_{el}(1 - |\cos \varphi(t)|);$$

Moreover: $r_{el}(t) = \frac{b}{\sqrt{1 - \left(1 - \frac{b^2}{a^2}\right) \cdot \cos^2 \varphi(t)}}$;

$$\varphi(t) = \varphi_m \cdot \sin(A_{2i}(t)),$$

where φ_m – maximum angle of deflection of the cutter, deg.;

$$\varphi_m = \frac{360 \cdot e}{h};$$

$b = R/2$ – minor semiaxis;

$a = \frac{R}{2 \cdot \cos \varphi(t)}$ – major semiaxis;

$A_{2i} = (t - 45^\circ) + \gamma(t)$ – conditional angle of deviation of the cutter from the plane of the processed section.

Fig. 5. Arbitrary position of the cutter in the processing section (a) and the position of the cutter at the end of the section (b) relative to the cross-section of the helical surface

Fig. 6. The relative position of the longitudinal section of the workpiece and the section of the cutter in the plane $X_2 O Y_2$ в зависимости от угла A_2 : a, b – major and minor semiaxes of an ellipse; r_{el} – the radius vector from the focus of the ellipse to the point of tangency of the sections; φ – the angle between the vertical and the normal to the workpiece surface at the point of contact

Making the substitution $t = A_1$ into (1), we can get the following condition:

$$K_a = -(e + r) \cdot \sin\left(\frac{\pi}{4}\right) \cdot \left(1 - \frac{\arctg\left(\frac{r}{e}\right)}{\arctg\left(\frac{r}{e}\right) + \frac{\pi}{4}}\right) - \frac{R}{2\sqrt{1 - \left(1 - \frac{\pi^2 e^2}{4h^2}\right) \cdot \cos^2\left(\frac{2\pi e}{h}\right)}} \left(1 - \left|\cos\left(\frac{2\pi e}{h}\right)\right|\right) \cdot \sin\left(\frac{3\pi}{4} - \arctg\left(\frac{r}{e}\right)\right) \geq 0, \quad (2)$$

where R – cutter radius, r – section radius, e – eccentricity, h – helical pitch.

Substituting the corresponding parameters of the helical surface and the radius of the cutter into expression (2), it is possible to determine, without carrying out experimental processing, whether the resulting sectional shape will correspond to the specified parameters. Applying the same expression with known geometric parameters of the cycloidal surface, it can be determined the maximum possible cutter diameter for machining, thereby ensuring the maximum rigidity of the technological system.

Experimental confirmation of the obtained limitations

To confirm the efficiency of the proposed criterion, we will conduct a series of machine experiments using the G-code verifier. For arbitrary geometric parameters of the helical surface and various values of the cutter diameter the resulting surface profiles are modeled, their geometry is analyzed, and the K_a criterion is calculated. The simulation results are presented in Table 1 and Table 2, where the calculated criterion K_a is set in accordance with the obtained profile of the screw surface.

Table 1. Simulation of processing with different parameters of the step and diameter of the cutter

Surface parameters, mm			Cutter diameter, mm					
Section diameter	Eccentricity	Pitch	40	20	16	10	6	2
15	15	100
			-8.44	-4.22	-3.38	-2.10	-1.26	-0.1
15	15	150
			-2.06	-1.03	-0.33	0.21	0.31	
15	15	200
			-0.25	-0.01	0.12	0.15	0.23	

Table 2. Simulation of processing with different parameters of the pitch and eccentricity

Surface parameters, mm			Eccentricity, mm					
Section diameter	Cutter diameter	Pitch	25	20	15	10	5	2
15	10	100
					-2.10	-0.31	0.11	0.12
15	10	150
			-3.84	-1.12	-0.52	0.04	0.14	0.11
15	10	200
			-0.78	-0.08	0.04	0.09		

Analysis of the experimental data presented in the tables shows that the geometrically correct profiles of the helical surface (highlighted by a frame) correspond to the positive values of the criterion K_a . Thus, we can conclude that the obtained analytical expression of the criterion is valid.

Also, a natural experiment was carried out, during which samples from the V95T aluminum alloy were processed with the following geometric characteristics: cross-sectional diameter 9.8 mm, eccentricity 3.4 mm, pitch 36 mm. Processing was carried out on a 4-axis horizontal CNC milling machine equipped with a rotary table. A series of 4 samples was processed (Fig. 7) using cutters of different diameters – 3, 4, 5 and 6 mm. The diameters of the cutters were selected using the proposed criterion. As a result, the geometry of the obtained parts in all 4 cases corresponded to the specified parameters.

Fig. 7. Samples of a helical surface, machined with a tool of various diameters

Conclusions

As a result of the study, a formalized criterion for assessing the compliance of the specified geometric parameters of the cycloidal helical surface with the technological capabilities of a special processing strategy was proposed. The expression obtained analytically for this criterion was confirmed using a machine experiment, during which the treatment of surfaces with various parameters was simulated, and the results were compared with the calculated values of the criterion. The efficiency of the criterion was also shown during experimental processing of a series of samples on a CNC machine. The formalized criterion can be integrated into an automated system for calculating the tool path for processing cycloidal helical surfaces, which will significantly reduce the labor intensity of technological preparation of production.

Ethical Approval

The authors declare that this article has not been submitted to other journals for simultaneous consideration. The submitted work is original and not has been published elsewhere in any form or language (partially or in full). This study has not be split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time. Results have been presented clearly, honestly, and without fabrication, falsification or inappropriate data manipulation. The presented data, text and theories are original, not copied from the works of other authors and were developed by the authors of this article. The authors declare that they have permission for the use of software used in the article. The article cites appropriate and relevant literature, inappropriate self-citation and coordinated efforts among several authors to collectively self-cite were not used. Text of the article does not contain untrue statements about an entity or descriptions of their behavior. Submitted research cannot be misapplied to pose a threat to public health or national security. Author group, the Corresponding Author, and the order of authors are all correct at submission.

Consent to Participate

The authors agree to participate in the article submission and review procedure and to make all necessary edits if required.

Consent to Publish

The authors agree to publish the submitted materials in any form that the publisher deems necessary.

Authors Contributions

The corresponding author Goncharov A.A. has been responsible for writing this paper, developing of theory and experimental plan, measurements and analyzing all the obtained raw data. Vasiliev A.S. has been responsible for choice of research direction, formulation of the research problem and general research management.

Funding

No funds, grants, or other support was received.

Competing Interests

The authors declare that they have no conflict of interest.

Availability of data and materials

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and

your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- [1] Ponomarev B.B., Hien N.S. Finish Milling Dynamics Simulation Considering Changing Tool Angles. IOP Conference Series: Material Science and Engineering. 2018. V. 327. Is. 2. Article ID 022083. <https://doi.org/10.1088/1757-899X/327/2/022083>
- [2] Krasnyi V.A., Maksarov V.V. Improving Wear Resistance of Friction Assemblies of Oil-well Pumps Having Seals from Directionally Reinforced Polymer Composites. Chemical and Petroleum Engineering. 2017. V. 53 (1-2). P. 121-125. DOI: 10.1007/s10556-017-0306-x
- [3] Olt J., Liivapuu O., Maksarov V., Liivapuu A., Tärkla T. Mathematical Modelling of Cutting Process System. Springer Proceedings in Mathematics and Statistics. 2016. V. 178. P. 173-186. https://doi.org/10.1007/978-3-319-42082-0_11
- [4] Lebedev V.A., Serga G.V., Khandozhko A.V. Increase of Efficiency of Finishing-Cleaning and Hardening Processing of Details Based on Rotor-Screw Technological Systems. IOP Conference Series: Material Science and Engineering. 2018. V. 327. Is. 4. Article ID 042062. <https://doi.org/10.1088/1757-899X/327/4/042062>
- [5] Ryazantsev V.M. Rotorno-Vrashchatel'nyye Nasosy s Tsikloidal'nymi Zatspleniyami (Rotary Pumps with Cycloidal Gearing, in Russia). Publishing house "Mechanical Engineering", Moscow. 2005. 346 p.
- [6] Alekseeva L.B., Maksarov V.V. Evaluation of Effect of Oil Film of Rotor Bearing. IOP Conference Series: Material Science and Engineering. 2018. V. 327. Is. 2. Article ID 022003. <https://doi.org/10.1088/1757-899X/327/2/022003>
- [7] Sacher C., Pössnicker D. Low-Shear Dosing of Micro-Encapsulated Adhesives. Adhesion Adhesives & Sealants. 2013. V. 10. Is. 2. P. 21–23. doi:10.1365/s35784-013-0158-5
- [8] A.A. Goncharov, A.S. Vasiliev. Modern Methods of Screw-Type Pump Rotors Helical Surfaces Processing. Vestnik Rybinskogo Gosudarstvennogo Aviatsionnogo Tekhnicheskogo Universiteta imeni P.A. Solov'yeva (Bulletin of the Rybinsk State Aviation Technical University named after P.A. Solovyova, in Russia). 2017. V. 1 (40). P. 202-208.
- [9] Maksarov V.V., Keksin A.I. Technology of Magnetic-Abrasive Finishing of Geometrically-Complex Products. IOP Conference Series: Material Science and Engineering. 2018. V. 327. Is. 4. Article ID 042068. <https://doi.org/10.1088/1757-899X/327/4/042068>
- [10] Goncharov A.A., Vasilev A.S., Gemba I.N. The Method of Machining Multiple-Helical Surface of Screw Pump Rotor Using CNC Milling Machines. SPRAVOCHNIK. Inzhenernui Zhurnal (HANDBOOK. An Engineering Journal, in Russia). 2017. V. 4. P. 8-16. DOI: 10.14489/hb.2017.04.pp.008-016

Figures

Figure 1

Screw pump for pumping oil products

Figure 2

Section of high-precision single-screw dispenser

Figure 3

Section of high-precision single-screw dispenser

Figure 4

The processing results corresponding to the specified parameters (a) and having form deviations (b, c)

Figure 5

Arbitrary position of the cutter in the processing section (a) and the position of the cutter at the end of the section (b) relative to the cross-section of the helical surface

Figure 6

The relative position of the longitudinal section of the workpiece and the section of the cutter in the plane $X_2 O Y_2$ в зависимости от угла A_2 : a , b – major and minor semi-axes of an ellipse; rel – the radius vector from the focus of the ellipse to the point of tangency of the sections; φ – the angle between the vertical and the normal to the workpiece surface at the point of contact

Figure 7

Samples of a helical surface, machined with a tool of various diameters